***Tectonic Earthquakes of the Pacific Northwest***

*The Pacific Northwest is host to three kinds of tectonic earthquakes :*

1. *magnitude nine Cascadia megathrust quakes*
2. *Magnitude 6.5­ to seven deep earthquakes , and*
3. *Shallow crustal-fault earthquakes with magnitudes up to 7.5.*

*What causes them?.*

*We will show how subduction of the Juan de Fuca plate: basin & range extension, invasion of crustal blocks from California, and the resistance of the Canadian crustal buttress combine to produce these earthquakes.*

We begin by looking at Western North America’s active plate boundaries The San Andreas Fault is a strike-slip transform fault zone along which the Pacific Plate is sliding northwest at about 3.5 cm/yr with respect to interior North America. The Pacific Plate drags on that plate margin, and segments of the boundary rupture sporadically releasing moderate to large earthquakes. The most famous was the 1906 magnitude 7.8 San Francisco earthquake, a 480-km-long rupture.

North of the San Andreas fault, the Juan de Fuca Plate dives *beneath, and pushes on* the margin of the North American Plate. Rates of convergence range from 3.0 to five cm/yr. On January 26, 1700 a magnitude-9 Great earthquake ruptured the full **1,000** km length of that plate boundary. Magnitude eight to nine great earthquakes rupture the subduction zone on average every 300–500 years.

How do we know energy is building for a future great earthquake? 142 The ongoing compression of the Cascadia continental margin is being measured by GPS. Data, represented by arrows, show coastal stations moving northeast faster than inland stations. Looking at this in cross section, we’ll use a spring to represent the elastic nature of the overriding plate locked to the diving plate. The graphs show the motions of three GPS stations as the continental margin is compressed and elastic energy builds. When friction ***between*** the plates is overcome, the leading edge of the North American Plate lurches seaward generating an earthquake and tsunami.

Next we look deeper, at earthquakes ***within*** the subducting Juan de Fuca Plate itself. The 1949 magnitude 6.8 Olympia earthquake caused 8 deaths. Fortunately it occurred during school spring vacation as 10 schools were severely damaged and subsequently closed.

The hypocenter of the Olympia earthquake was 52 km deep, at least 7 km BELOW the subduction zone plate boundary and thus WITHIN the subducting Juan de Fuca Plate. As the subducting plate bends beneath Puget Sound, the upper part stretches under tension and fractures in normal faults.

In 1965, a magnitude 6.5 deep earthquake occurred 60 km beneath **Seattle** killing 7 peopleand causing 100 million dollars in damage.

The 2001 magnitude 6.8 Nisqually earthquake was identical to the Olympia earthquake and may  same normal fault. Strong ground shaking in the Puget Sound basin lasted over 30 seconds and caused one death, 400 injuries, and damaged 40 bridges and 300,000 buildings.

Deep earthquakes occur every 20 to 30 years beneath the Puget Sound, and can occur along the length of Cascadia where the subducting plate bends to dive more steeply.

Aside from the forces applied by the Pacific and Juan de Fuca plates along the boundaries, more is going on ***within*** the internally deforming North American plate.. As the subduction zone is locked and elastic energy builds.we expect to see deformation of the continental margin, as shown by these **yellow** arrows, However, this deformation is reversible because the edge of the North American Plate jumps back to the west during each great earthquake before it locks again and begins reloading. If the load-and-release great earthquake cycle was the only deformation, the observed GPS motions would be this simple pattern shown by the yellow arrows. However, the ***measured*** GPS motions are more complex indicating that Cascadia deformation is a far more interesting story.

Let’s look at that.

Basin & range extension stretches from western Utah into southeastern Oregon To the west, the Sierra Nevada Block, ***dragged north-northwest by the Pacific Plate*,** is pushing on the Oregon Coast Range Block that in turn pushes on the Washington crustal block. The resisting Canadian Coast Mountains halts the motion. These forces rotate much of western Oregon and Washington ***slowly*** about a pivot point in northeast Oregon.: Unwinding sixteen million years lets us SEE the permanent deformation caused by this rotation.

The resulting deformation has broken the crust by normal, strike-slip, and thrust faults with motion histories that are the focus of ongoing research.

An important example is the Seattle FaultZonethat extends across the heavily populated southern Puget Sound area. Trenching, shown in the photo, provides direct evidence of south-side-up thrust fault displacement **from** a major M7 or 7.5 earthquake on the Seattle Fault about 1000 years ago. This animation depicts exaggerated thrust faulting along the Seattle fault zone.

Modeling of ground motions that would result from a M7.2 earthquake here sobering. Areas within a few miles of the Seattle Fault, including much of Seattle, would experience 20 seconds of severe ground shaking, an amount shown in this full-scale shake-table experiment.

How does shaking from the shallow Seattleearthquake differ from a deep one like the 2001 Nisqually earthquake? Because the hypocenter at Nisqually was 52 km deep, the seismic energy spread out beyond the Puget sound rather than concentrated near the epicenter as it would for a shallow earthquake. A magnitude 7 event has up to twenty seconds of severe ground shaking.

A subduction zone megathrust earthquake, like Japan experienced in 2011, will have the broadest impact. A magnitude 9 earthquake releases the equivalent energy of four magnitude-7 earthquakes *every second* over a rupture interval of *4 minutes*! Projected ground shaking for that event will be severe at the coast but still very strong in the urban corridor, where ground shaking can last for over six minutes with slow back-and-forth motions, particularly challenging for tall and long structures. The tsunami comes ashore 15–20 minutes after ground shaking stops.

The Pacific Northwest is a region of high earthquake risk because of megathrust earthquakes on the plate boundary, deep earthquakes *within* the subducting plate, and shallow crustal earthquakes. By putting them all together scientists are able to create an earthquake hazard map for the region.

Amplified ground motion in the sediment-filled basins of the urban corridor are of concern for all earthquakes. Exterior walls of unreinforced masonry buildings constructed before modern building codes often crumble during earthquakes. Instinctually people run out of buildings during ground shaking and are often killed or injured by falling debris. The life saving response is to drop, cover, and hold until shaking stops. Earthquake and tsunami education along with construction of earthquake-resilient buildings and infrastructure are vitally important in this seismically active region.